Long-term monitoring of soundscapes and deciphering a usable index: Examples of fish choruses from Australia

Miles Parsons, Christine Erbe, Robert McCauley, James McWilliam, Sarah Marley, Alexander Gavrilov, and Iain Parnum

Citation: Proc. Mtgs. Acoust. **27**, 010023 (2016); doi: 10.1121/2.0000286

View online: https://doi.org/10.1121/2.0000286

View Table of Contents: http://asa.scitation.org/toc/pma/27/1

Published by the Acoustical Society of America

Proceedings of Meetings on Acoustics

Volume 27 http://acousticalsociety.org/

Fourth International Conference on the Effects of Noise on Aquatic Life

Dublin, Ireland
10-16 July 2016

Long-term monitoring of soundscapes and deciphering a usable index: Examples of fish choruses from Australia

Miles Parsons, Christine Erbe, Robert McCauley, James McWilliam, Sarah Marley, Alexander Gavrilov, and **Iain Parnum**
Centre for Marine Science and Technology, Curtin University, Perth, WA 6102, Australia,
m.parsons@cmst.curtin.edu.au; c.erbe@curtin.edu.au; rob.McCauley@curtin.edu.au; mcwilliamjamie@googlemail.com; sarah.marley86@gmail.com; a.gavrilov@curtin.edu.au; i.parnum@cmst.curtin.edu.au

Similar to geophysical and anthropogenic noise, biological contributions to soundscapes vary considerably in frequency, time, and intensity. Fish choruses are a perfect example, contributing significantly to marine biological noise and are used here as an analogue for variations in soundscapes. Their species-characteristic signals vary thus, so do their choruses, which can raise ambient noise levels by up to tens of decibels, for prolonged periods. Multi-species choruses can occur, with varying degrees of temporal and frequency partitioning, or none at all. Australian datasets of underwater noise have been acquired for nearly two decades and multiple fish calling patterns have been detected. Detecting, delineating, and understanding these patterns is non-trivial and a metric relating their contribution to the soundscape with biodiversity or habitat would be an invaluable tool. In recent years, several acoustic indices have been derived, proving useful in the terrestrial domain. Investigation of their application in marine environmental studies has also begun. However, such a plethora of widely varying sources and changing patterns can affect acoustic indices. This paper describes a simple and automatic suite of tools to help identify signals of a wide range of time patterns which are potentially underrepresented or missed by acoustic complexity or biodiversity indices.

Published by the Acoustical Society of America

 [DOI: 10.1121/2.0000286]

1. INTRODUCTION

The underwater acoustic environment comprises a number of contributions, which make up the local 'soundscape' (Schafer, 1993; Krause, 1999). These sounds may be biological (biophony, e.g., originating from fish, mammal, or invertebrate sources), geophysical (geophony, e.g., caused by wind, rain, and earthquakes), or anthropogenic (anthrophony, e.g., vessel, construction, or seismic exploration noise) in origin. Thus soundscape ecology, the measurement and understanding of these acoustic components and how they relate to the physical environment and ecology, holds the potential to provide a wealth of information.

The premise behind acoustic and biodiversity indices is that biological sounds are characterized by intrinsic variability in frequency and intensity, while anthropogenic sounds remain comparatively consistent (Farina and Morri, 2008). Acoustic complexity and biodiversity indices assess changes in acoustic energy in the time or frequency domain (or both) as an analogue for the number of vocalizing individuals or number of species in the area. The greater the variability in the soundscape, the more likely it is to result from biological sounds, the higher the index. This is then thought to provide an indication of the species richness or the overall health of the local ecosystem. In the terrestrial environment, this study of ecoacoustics has already proven a valuable tool for assessing local biodiversity, where a large number of such indices have already been defined (Pieretti et al., 2011; Sueur et al., 2014). The exploration of how applicable these indices are within the marine environment has begun (McWilliam and Hawkins, 2013; Harris et al., 2016; Kaplan et al., 2015).

Before drawing conclusions on how acoustic indices relate to the aquatic fauna in the habitats from which they are derived, there is a pressing need to understand soundscape spatio-temporal patterns and how these can affect each index. Some recent attempts have begun to assess whether individual indices are susceptible to anthrophony and geophony (Harris et al., 2016). However, as marine biological signals occur over a broad frequency range, it is also necessary to assess to what extent each index is affected by biological sources of different spectral or temporal content. Some acoustic events, such as fish choruses, can involve one or more species calling for prolonged periods. A single chorus type or a group of choruses may be acoustically complex, but as the cacophony of signals begins to resemble random noise, they may also raise ambient noise levels significantly, without increasing the long-term acoustic complexity. In addition, as acoustic indices attempt to compress all the information from the soundscape through time into a single number, there is a risk of missing acoustic events of short duration, either because they contribute too little to be detected over the entire dataset, or the recording sampling regime is not sufficient to detect them in the first place. This is important if the acoustic event is a cue for a related short-time event, such as if larval recruitment for a coral reef peaked over a comparatively short period (Meekhan et al., 1993) and recruitment levels were related to the local soundscape (Simpson et al., 2005).

For nearly two decades, datasets of underwater noise have been acquired around Australia by the Centre for Marine Science and Technology. The Australian Integrated Marine Observing System (IMOS, http://imos.org.au) has provided publicly available soundscape recordings from a handful of locations for nearly a decade (e.g., Erbe et al., 2015, 2016; McCauley and Cato, in press). In addition to numerous other acoustic studies, this has supported the study of fish choruses and their occurrence relative to environmental factors. Fish and invertebrates are some of the most prolific contributors to underwater sound. Therefore understanding how they contribute to the local soundscape over different time scales, and what these patterns tell us about local ecosystem health and diversity, is a major step towards quantifying the local ecosystem through passive acoustic

measurement. Multiple fish calling patterns have been compared to environmental correlates to understand what drives their presence, timing, and level (up to 40 dB above background ambient noise levels) over seasonal (wet/dry, summer/winter), semi-lunar and lunar, and diel (solar, tidal) cycles (McCauley, 2001; Parsons, 2010; McCauley, 2012; Parsons et al., 2016a; McCauley and Cato, in press). Multiple choruses from different species can occur together, with varying degrees of temporal and frequency partitioning or none at all (Parsons et al., 2013, 2016b) and calling locations may move onshore/offshore, along coastlines or around river systems, as the fish move to spawn, feed, or migrate (Parsons et al., 2015, 2016b). These fish choruses offer examples of timescales by which biological sources can occur and illustrate parameters that any acoustic index, or suite of indices, needs to incorporate to provide useful representations of the overall ecosystem.

This study presents a simple tool to help identify signals of vastly different time patterns that are potentially missed by acoustic complexity or biodiversity indices, in order to better understand the occurrence and ultimately function of animal calls and choruses.

2. METHODS

Reported fish choruses were compared from a number of sites around Australia to determine if they exhibited the same characteristics or spatio-temporal differences in either sound pressure levels of spectral content. In example cases the timing of daily peak calling and levels throughout the month were compared. To investigate ways to discern and quantify differences in soundscapes from different sites, example recordings were taken from: 1) a temperate estuary; 2) a tropical estuary; 3) tropical nearshore reef; 4) tropical offshore reef 5) tropical coastal site. The recordings included various types of biological and anthropogenic sound, occurring over different timeframes and with different signal characteristics including: 1) with and without a mulloway (*Argyrosomus japonicus*) chorus comprising energy predominantly between 100 and 700 Hz (Parsons et al. 2013); 2) seismic and vessel noise; 3) fish chorus around 250 Hz; 4) fish chorus around 1 kHz; and 5) fish choruses at 250 Hz and 1 kHz.

Recorded time series were calibrated and then Fourier transformed using a 1 s FFT window yielding power spectral density (PSD). As a first step in soundscape analysis, long-term spectrograms were inspected using CHORUS (Gavrilov and Parsons, 2014). Spectra were averaged over the duration of each recording (duty cycle was typically 200-300 s recordings repeated every 900 s) and PSD percentiles (PSD%) were computed for the entire dataset. Power spectral probability density (PSPD) for each dataset was plotted together with the PSD%, as per Merchant et al. (2013), to assess the overall contribution of sources to the long-term soundscape. Given the variability in diel patterns that have been previously reported, analysis was conducted on entire days, rather than a specific period of the day. The PSD% plots of the entire recording detect the contributions of choruses at the extreme percentiles even if they only occur for a small period of each day.

To investigate the potential impacts of temporal patterns in biological signals on an acoustic index, a matrix was created to show how signal spectra and duration might change soundscape complexity. PSD was averaged over time windows of increasing length, and the level differences between successive time windows were investigated at a series of 1/3-octave bands. The absolute differences between consecutive 1 s averages were calculated for each 1/3-octave band. These differences were then averaged across each recording (e.g., for the 300 s of each 900 s recording, 299 absolute differences between the 300 consecutive windows were averaged). The process was then repeated six times using 2, 4, 8, 16, 32, and 64 s time-averaging windows. Band-levels might differ depending on when the averaging window starts. Therefore, for the 2, 4, 8, 16, 32, and 64 s windows, calculations were conducted multiple times, with a starting point repositioned, each time

delayed by 1 s. For the example of a 2 s window, the differences in bandlevels between successive windows were computed twice, once starting at the beginning of the recording, and once starting 1 s into the recording. The average of the successive differences was computed for each of the two series, and the larger average was kept as the maximum average difference in bandlevels for a 2 s analysis window. For the 4 s analysis window, successive bandlevel differences were computed three times, once starting at the beginning of the recording, once offset by 1 s, once offset by 2 s, and once offset by 3 s. The maximum of the average differences in bandlevels was kept. The longer windows were treated in the same manner. For comparisons over greater timescales than a single duty cycle, consecutive recording cycles can be compared in the same way.

As a means of assessing the likelihood that the majority of loud and quiet events were captured in long-term recordings, the dataset's dynamic range was computed cumulatively, adding one recording at a time (Erbe et al., 2016). PSD% were calculated for the first 300 s recording, and then repeatedly by adding every subsequent 300 s recording. As more 300 s recordings are included, the spread of PSD% levels increases. The dynamic range was defined as the difference between the 1st and 99th PSD levels, averaged over the full frequency band.

3. RESULTS

An example spectrogram showing a 20-day recording at a temperate river site is shown in Fig. 1, highlighting some diel patterns of biotic and anthropogenic noise.

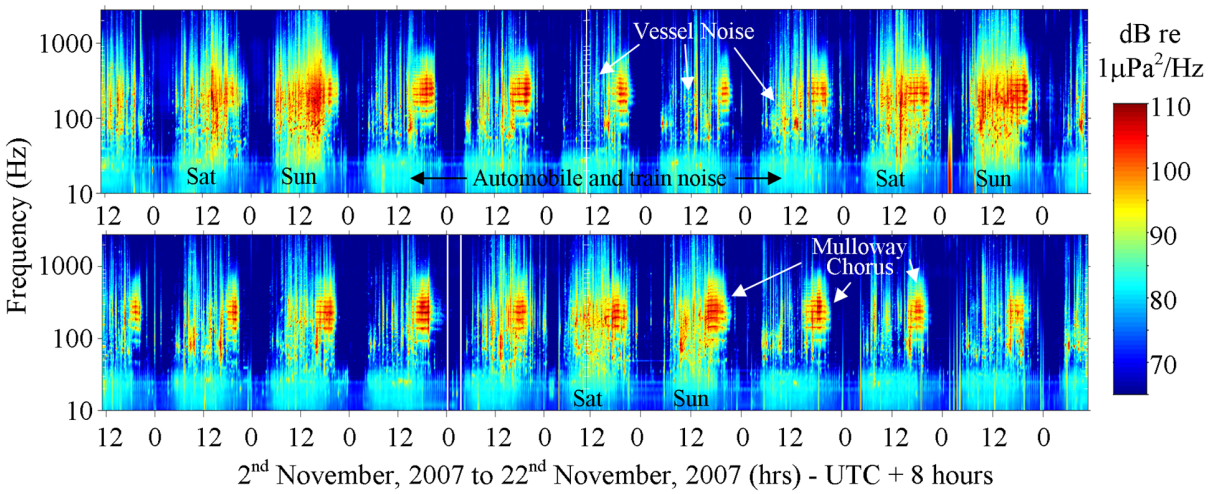

Figure 1. Stacked spectrograms of 20 days of recordings from a temperate estuary in Western Australia, with broadband vessel signals (peaking on the weekend), speculated ground-borne terrestrial energy and amplitude-modulated fish (mulloway) choruses.

Similar chorus types, at different locations, were found to occur at very different times of day or peak at different times of the lunar cycle month (Fig. 2a and b, respectively). Species-characteristic chorus spectra can vary significantly (Fig. 2c) and differ between sites. Calls with either harmonics or sidebands of amplitude modulation will have different impacts on acoustic complexity in the frequency domain than more broadband signals and these effects will be dependent on the frequency bands chosen for analysis (e.g., compare Fig. 2c blue line with pink line). Even choruses thought to originate from the same or similar sources were found to differ in received levels and spectra related to positional conditions of source, receiver, and local bathymetry, along with conditions impacting transmission.

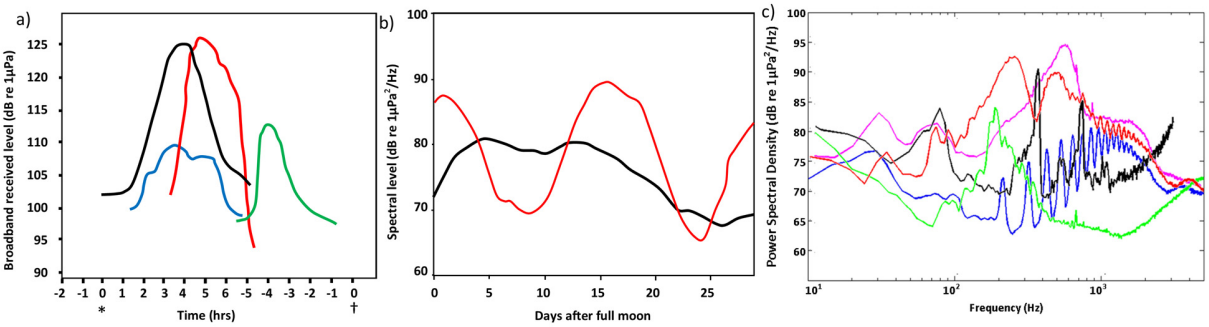

Figure 2. a) stylised broadband levels for four speculated Terapontid choruses recorded in a tropical estuary (black line, Parsons et al. 2016a), tropical coastal (red line) and tropical offshore reef (blue line, Parsons et al., 2016b) and off a tropical nearshore reef (green line, McCauley 2012) in relation to sunset (*) and sunrise (†). b) Stylised spectral levels over the chorus period from speculated planktivoros fish at a tropical offshore reef (black line) and tropical nearshore reef (red line) from northwestern Australia, in relation to days after the full moon (McCauley and Cato 2016). c) Power spectral densities of five example chorus types from tropical estuary and tropical coastal sites (McCauley 2012; Parsons et al. 2016a, 2016b).

The power spectral probability density plots in Fig. 3 further illustrate the contributions of different types of choruses to soundscapes at different sites and over varying periods. Given the variability in diurnal patterns, these examples were analyzed including full days, including all data within the recording period, rather than assessing particular times of the day, such as the crepuscular period. Choruses at the tropical offshore reef (e.g., Fig. 3a-d yellow and orange boxes) varied across the lunar period, though only above the 75th percentile, with the lower frequency chorus showing a progressive decline from new to full moon while the higher frequency chorus peaked between the full moon and new moon phases. The median levels were similar throughout days when the choruses were most prominent to the overall recording period for the season, thus the difference between the median and the higher percentiles indicate the level of contribution the fish chorus has to the soundscape. The temperate estuary PSPD plots, which include a particularly intense chorus of a single species, mulloway (*Argyrosomus japonicus*), also showed differences between summer and winter, this time increasing the median levels at the peak spectral frequency of the chorus (≈300 Hz) by over 20 dB (Fig. 3e and f), due to the intensity, duration, and frequent occurrence of the chorus. By contrast, the tropical estuary recording, which contains choruses from several species of fish (Parsons et al., 2016a) produced similar density plots for the upper percentiles between the wet and dry season in terms of levels (Fig. 3g and h). Across the seasons, median levels increased by ≈5 dB at frequencies where the fish choruses were most prominent, yet the lower percentiles increased by ≈10 dB. These changes are indicative of a chorus that occurs throughout the year, though more intensely through the wet season and more regularly through the dry season.

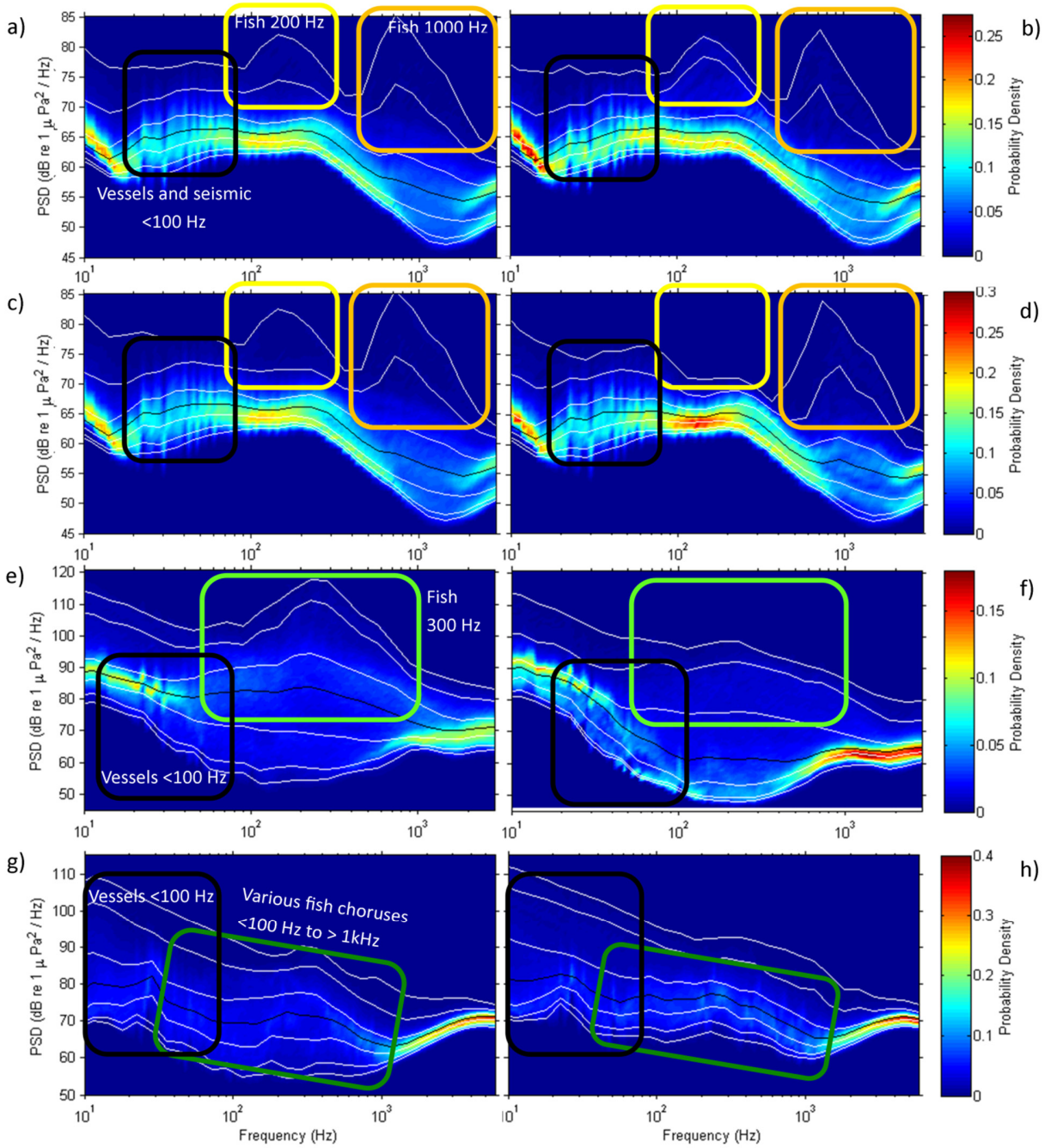

Figure 3. Probability of power spectral density for different soundscapes including tropical offshore reef over a whole wet season, around new moons, between moons, and around full moons (a, b, c and d, respectively), a temperate estuary across summer (e) and winter (f), and a tropical estuary in a wet (g) and dry (h) season. White lines show the 1st, 5th, 25th, 50th (black line), 75th, 95th, and 99th percentiles, from the bottom to the top of each image, while colors show probability of a received level occurring at each frequency across the time periods.

The three examples of the dynamic range indicator (DRI) from alternative sites in Fig. 4 show how difficult it can be to ensure that all of the important acoustic signals (including seasonal choruses) have been captured. The rate of change in dynamic range as the recording progresses is partly dependent on the ambient noise levels at the start of the recording, thus the slope and

asymptote can vary (Fig. 4a and b). However, Fig. 4c shows that an extreme level event, such as a fish chorus, can occur at any time throughout the entire dataset. This highlights that unforeseen acoustic events may occur, even when it looks as though the significant signals have all been accounted for.

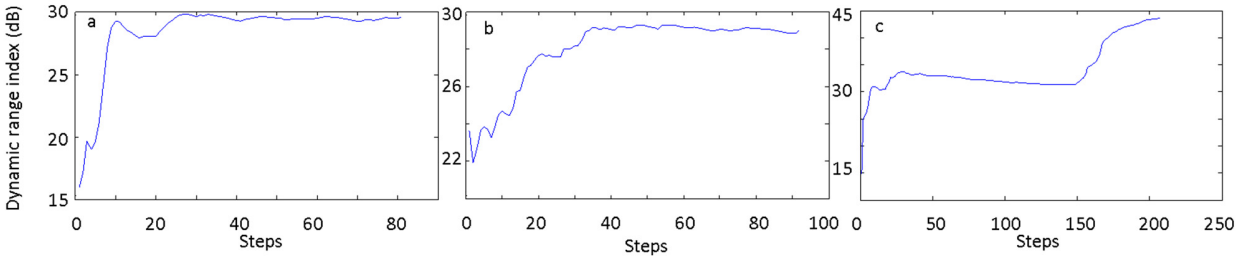

Figure 4. Maximum variation of dynamic range observed when the sample duration is increased with examples of a quick rise (a), slow rise (b) and a quick rise, with a late unexpected acoustic event, such as a fish chorus (c).

Figure 5 illustrates how a tool, such the signal duration matrix, could identify the impacts of different signal types, using the tropical reef soundscape and its biophony as an example. Periods where multiple individual pulsed signals (fish chorus) combined to increase the ambient noise levels significantly, but barely changed the temporal complexity were common (Fig. 5c and e, black boxes). Loud, broadband impulsive signals can affect not only in the short time-average window (1 or 2 s), but the longer time-averaged windows as well (Fig. 5f, up to 32 s, green box). Repetitive impulsive signals can be detected, even if ambient noise are raised by a limited amount (Fig. 5b, yellow box) and changes in the grouping of these signals can be picked up across the longer time-average signal (Fig. 5d, orange box). Fig. 5 also highlights how variable the very low frequencies (<20 Hz) are throughout typically all of the recordings (grey-blue boxes) and thus may require further processing.

4. DISCUSSION

In the underwater world, sound, rather than sight, is the main sensory modality for many species. As a result, marine soundscapes are complex mixtures of acoustic signals, which display a wide range of temporal and spectral characteristics. For example, while the capability for individual variation in fish sound production may be comparatively small, the variety of interspecific signals is substantial and their combined influence on the soundscape with range, propagation, and temporal patterns at any given recording site is complex. When attempting to condense this information into a single or handful of indices, significant contributions may be missed. There are very simple and automatic ways to provide an overview of the soundscape and the contributing signals, such as the PSPD plots and signal duration matrix presented here. A DRI provides an additional tool to qualitatively assess the likelihood that all significant acoustic events have been incorporated in the sampling. While they themselves may not quantify the soundscape, they can provide invaluable information to help evaluate those that attempt to.

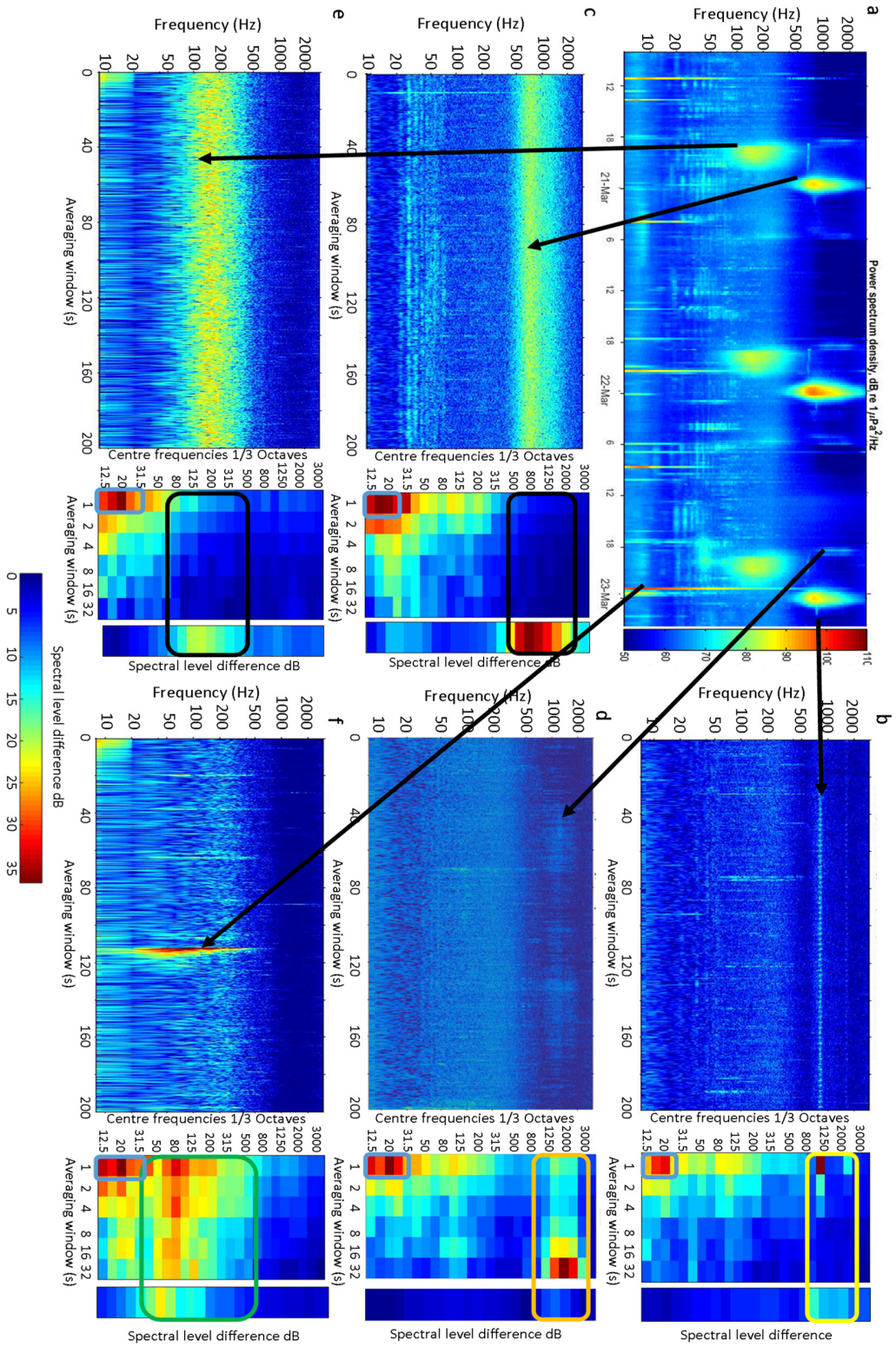

Figure 5. 3-day spectrogram from waters off an Australian tropical offshore reef (a) with expansions of individual sample periods (b-f). To the right of each expanded spectrogram are color plots of mean absolute differences between consecutive samples across the recording for different time averaging windows and 1/3-octave frequency band (middle plots), followed by the difference between the 1/3 octave level in the sample and that of the quietest single sample from the three days of recording. Points of interest are highlighted in the text.

Acoustic index performance is affected by temporal and spatial patterns. Similar to long-term datasets reported elsewhere, acoustic recordings around Australia have illustrated the variety of temporal patterns present in fish choruses, whether individual or multiple species (McCauley, 2001; 2012; Parsons, 2010; Parsons et al., 2013, 2014, 2016a). Similar chorus types at different locations may occur at very different times of day or month. Day-to-day chorus presence and level may also be significantly influenced by tidal levels, sometimes to an extent that daily timing may shift by a number of hours within a few days (Parsons, 2010; Parsons et al., 2016a). Received levels of choruses have correlated with patterns of geophysical variables (Parsons 2010, 2016a), and some evidence suggests that sounds attributed to offshore feeding fish may be associated with light (McCauley and Cato, in press). Further, these are all observed variations from individual chorus types, yet species-characteristic chorus spectra can vary significantly, adding to the complexity of these patterns. Sources levels can differ significantly between species (Parsons et al., 2012, 2014; Luczkovich and Sprague, 2004) and within a species, for example with temperature (Connaughton et al., 2000). Individual fish calls can be broadband pulses, tonal with harmonics, or even exhibit numerous sidebands of amplitude modulation depending on sampling frequencies and fast Fourier transforms employed in analysis (Parsons et al., 2016a, 2016b).

As with reports elsewhere, even some of the most predictable and characteristic sources, such as the coastal evening chorus and crepuscular reef activity of snapping shrimp have shown unexpected spatial and temporal variation (Fisher-Pool, 2015; Lillis et al., 2016; McCauley and Cato, in press). Similarly, in the coastal environment, a number of choruses have appeared for periods of a few days to weeks in waters off Port Hedland, with the spatial separation between two recording sites suggesting along coast movement (Parsons et al., 2016b). In addition, signal transmission between source and receiver is highly dependent on range, bathymetry, and water-column position of both. Together with several geophysical parameters, these can impact transmission such that two sets of similar signals can have different received spectra, depending on transmission at the time of calling (McCauley, 2012). Thus even source locations can influence the performance of an acoustic index.

Soundscape variations can range in period, intensity, and spectral content, originate from a multitude of sources, and relate or respond to numerous environmental and anthropogenic factors that might interact. Marine soundscapes are multi-source, multi-driver, multi-response, on a multi-frequency, multi-circa scale and what their components mean to the recipient is biologically (species-specific hearing abilities), behaviorally (associated function), temporally (point in life-cycle), spatially (location and propagation of source and recipient), and environmentally dependent. Therefore, summarizing these complexities down to one or two acoustic indices is non-trivial and requires caution. If an index for environmental diversity or health is to be obtained from an acoustic recording, it is necessary to understand how these variations may contribute to changes in that index. Thus, before deriving an index or a suite of indices, this paper has focused more on creating a format under which researchers can identify variations over a wide range of time-scales so that underlying drivers can be interpreted and identified.

The signal duration matrix is a simple tool which, when combined with the PSPD plots and the DRI, can provide valuable information on what types of signals are significantly contributing to the soundscape whether in complexity or energy, short or long duration, and over what frequency band(s). It provides information on absolute differences between samples and spectral level above ambient noise for each sample. Patterns within this matrix and their independent shapes/intensity are then indicative of the acoustic complexity and received level above background noise over a given sample duration, across different temporal scales. While these do not provide a quantitative measure, they do provide support for whether particular signals, such as fish choruses, are likely to have contributed to variations in an acoustic index. It is hoped that this tool could lead to a suggested

means of quantitatively characterizing the types of sounds at a given site. There is still the issue of missing acoustic events that may contribute significantly to the soundscape, however, the levels of their impact can be estimated if the probability of the power spectral density and the number of samples with maximum dynamic range are known.

The marine world contains a large number of species that rely on acoustic communication either through sound production or audition, emitting and responding to a variety of signal types. This raises the question of whether any metrics derived from these need to be species or environmentally specific. As identified by Sueur et al. (2014), one acoustic measure is unlikely to be sufficiently descriptive of the soundscape to draw many useful conclusions without prior knowledge of what is contributing to the soundscape. However, a suite of useful indices would be a valuable tool for quantifying the relationship between soundscape and ecosystem. Harris et al. (2016) suggested four criteria to be met for an underwater acoustic index to be successful, namely: 1) be positively correlated with traditional species assemblage measurements in relevant frequency ranges; 2) be robust to changes in spectral resolution; 3) be robust to the inclusion of natural noise interference (e.g., wind) in the acoustic data set; and 4) be robust to the inclusion of anthropogenic noise interference in the acoustic data set. However, a fifth criterion should be added and that is that it should be robust to the temporal variations in biophony and geophony commonly exhibited in the acoustic data set.

REFERENCES

Connaughton, M.A., Taylor, M.H., and Fine, M.L. (**2000**). "Effects of fish size and temperature on weakfish disturbance calls: Implications for the mechanism of sound generation," J. Exp. Bio. **203**, 1503-12.

Erbe, C., Verma, A., McCauley, R., Gavrilov, A., and Parnum, I. (**2015**). "The marine soundscape of the Perth Canyon," Prog. Ocean. **137**, 38-51.

Erbe, C., McCauley, R., Gavrilov, A., Madhusudhana, S., and Verma, A. (**2016**). "The underwater soundscape around Australia," Proceedings of Acoustics, 9-11 November 2016, Brisbane, Australia.

Farina, A., and Morri, D. (**2008**). "Source-sink e eco-field: ipotesi ed evidenze sperimentali. Atti del X congresso nazionale della SIEP-IALE. Ecologia e governance del paesaggio: esperienze e prospettive," Bari., 365–372.

Fisher-Pool, P. (**2015**). "Does chlorophyll-A turn up the volume?: Exploring the relationship between oceanographic parameters and coral reef soundscapes," Masters Thesis, University of Hawaii, Honolulu, pp. 31.

Gavrilov, A.G., and Parsons, M.J.G. (**2014**). "A Matlab toolbox for the Characterisation Of Recorded Underwater Sound (CHORUS)," Acoust. Aust. **42**(3), 191-196.

Harris, S.A., Shears, N.T. and Radford, C.A. (**2016**). "Ecoacoustic indices as proxies for biodiversity on temperate reefs," Methods Ecol. Evol. **7**, 713–724

Kaplan, M.B., Mooney, T.A., Partan, J., and Solow, A.R. (**2015**). "Coral reef species assemblages are associated with ambient soundscapes," Mar. Ecol. Prog. Series. **533**, 93-107.

Krause, B., (**1999**). "Loss of Natural Soundscapes Within the Americas," Wildlife Sanctuary Inc., 10 pp. (Online) Retrieved 12 July 2009. www.wildsanctuary.com/bk asa.pdf.

Lillis, A., Eggleston, D.B., and Bohnenstiehl, D.R. (**2016**). "Soundscapes and Larval Settlement: Characterizing the Stimulus from a Larval Perspective," (Eds., Popper, A. and Hawkins, A.) In *The Effects of Noise on Aquatic Life II,* Volume 875 of the series Advances in Experimental Medicine and Biology, Springer New York, pp. 637-645.

McCauley, R.D., and Cato, D.H., "Evening fish choruses in the Perth Canyon and their potential link with Myctophidae fishes," (in press, J. Acoust. Soc. Am.) .

McCauley, R. D., (**2001**). "Biological sea noise in northern Australia: Patterns of fish calling, PhD Thesis. James Cook University of North Queensland," 290 pp.

McCauley, R. D., (**2012**). "Fish choruses from the Kimberley, seasonal and lunar links as determined by long term sea noise monitoring," *In Proceedings of Acoustics 2012* - 21–23 November 2012, Fremantle, Australia. 6 pp.

McWilliam, J. N., and Hawkins, A. D. (**2013**). "A comparison of inshore marine soundscapes," J. Exp. Mar. Bio. Ecol. **446**, 166-176.

Meekan, M.G., Miliciche, M.J., and Doherty, P.J. (**1993**). "Larval production drives temporal patterns of larval supply and recruitment of a coral reef damselfish," Mar. Ecol. Prog. Ser., **93**, 217-225.
Merchant, N.D., Fristrup, K.M., Johnson, M.P., Tyack, P.L., Witt, M.J., Blondel, P., and Parks, S.E. (**2015**). "Measuring acoustic habitats," Methods Ecol. Evol. **6**, 257–265.
Parsons, M.J.G., (**2010**). *In An Investigation into active and passive acoustic techniques to study fish spawning aggregations,* PhD Thesis, Curtin University, Perth, 409 pp.
Parsons, M.J.G., McCauley, R.D., Mackie, M. and Duncan, A.J. (**2012**)." *In situ* source levels of mulloway (*Argyrosomus japonicus*) calls," Journal of the Acoustical Society of America, 132(5), 3559□68.
Parsons, M.J.G., McCauley, R.D. and Thomas, F. (**2013**). "Sound of fish calls off Cape Naturaliste, Western Australia," Acoust. Aust. **41**(1), 58-63.
Parsons, M.J.G., Longbottom, S.M., McCauley, R.D., and Fairclough, D.V. (**2014**). "*In situ* calls of Western Australian dhufish (*Glaucosoma hebraicum*)," Acoust. Aust. **42**(1), 31-35.
Parsons, M.J.G., Fairclough, D.V. and McCauley, R.D. (**2015**). "Passive acoustic techniques to monitor aggregations of sound producing fish species," Fisheries Research and Development Corporation Final Report, Project 2010/004. Curtin University, Perth, 164 pp.
Parsons, M.J.G., Salgado-Kent, C.P., Marley, S. and McCauley, R.D. (**2016a**). "Fish choruses in the Darwin Harbour, Northern Territory." (advanced publication, ICES Journal of Marine Science).
Parsons, M.J.G., Recalde-Salas, A., Salgado-Kent, C.P. and McCauley, R.D. (**2016b**). "Fish choruses in the coastal waters of Port Hedland, Western Australia." (in press, Bioacoust.)
Pieretti, N., Farina, A. and Morri. D. (**2011**). "A new methodology to infer the singing activity of an avian community: The Acoustic Complexity Index (ACI)," Ecological Indicators 11, 868–873.
Schafer, R.M. (**1993**). Destiny Books, Rochester, Vermont, pp. 308.
Simpson, S.D., Meekan, M., Montgomery, J., McCauley, R.D. and Jeffs, A. (**2005**). "Homeward Sound," Science. **308**(5719), 221.
Sprague, M.W. and Luczkovich, J.J. (**2004**). "Measurement of an individual silver perch *Bairdiella chrysoura* sound pressure level in a field recording," Journal of the Acoustical Society of America, 116(5), 3186-91.
Sueur, J., Farina, A., Gasc, A., Pieretti, N. and Pavoine, S. (**2014**). "Acoustic Indices for Biodiversity Assessment and Landscape Investigation," Acta Acust. Utd. Acus. **100**, 772 – 781.